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Policy Options

Extensions and alternatives to climate change impact valuation: on the critique of IPCC Working Group III's impact estimates

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ABSTRACT. The paper discusses valuation issues in the context of climate change impact estimation. Issues addressed are aggregation of damage costs over diverse regions (particularly equity-weighting), differentiation of per-unit values, willingness to pay versus willingness to accept compensation as a basis for valuation, and accountability for impacts. Numerical illustrations show that the damage cost estimates are quite sensitive to the assumptions made on these issues.

1. Introduction

A reasonable understanding of the likely impacts of climate change on human welfare is crucial for making an informed decision about the best response strategy to the enhanced greenhouse effect. For this reason, the Second Assessment Report (SAR) of the Intergovernmental Panel on Climate Change (IPCC) has paid particular attention to the study of impacts. Working Group II has extensively reviewed the literature on the physical impacts of climate change (Watson *et al.*, 1996).

However, in the view of some decision makers it is useful, and for some decision support tools it is necessary, to aggregate the vast number of detailed regional and sector-specific estimates to a more tractable set of numbers. Money is the most commonly chosen numeraire for this type of aggregation exercise, partly for reasons of convenience and partly because of the internal logical consistency of monetization based on the theory of human preference measurement. Monetization also has the advantage of expressing impacts in the same units of measurement as the cost of response measures, which in turn facilitates the comparison of the costs and benefits (avoided impact) of emission control. IPCC has responded to this need also, and the 'Social Costs Chapter' (Chapter 6) of the Working Group III SAR has reviewed the available monetary assessments of climate change impact (Pearce *et al.*, 1996).

The chapter on social costs was among the most controversial chapters of the entire SAR. Partly this was no doubt due to the still low quality of most estimates—a fact which is clearly recognized and emphasized in the chapter. Partly, it may also have had to do with presentation. Early drafts of the chapter were perhaps too heavy on academic jargon and could easily be, and were, misinterpreted by some. Many, perhaps most, of the original critics objected to the IPCC figures mainly because they felt that damage had been underestimated, without querying valuation as such. Others fundamentally opposed the notion of economic valuation and questioned its usefulness and ethical underpinnings. Particularly controversial was the valuation of climate-change-induced mortality risk.

This paper is one in a series prepared by some of the lead authors of IPCC WG III, Chapter 6. Fankhauser and Tol (1997) present impact figures consistently corrected for purchasing power parity. Fankhauser and Tol (1996) discuss recent methodological advances and trends emerging in work published since the finalization of the SAR. Tol and Fankhauser (1997) review the state of the art of climate change impact representations in integrated assessment models, extending beyond the static portrait painted in the social cost chapter. Fankhauser *et al.* (1997) discuss some welfare-theoretic foundation for damage aggregation and comparison and present aggregates for a wider range of ethical positions than the restricted utilitarian approach adopted in IPCC WG3 Chapter 6. Finally, Pearce (1997) and Tol (1997) ask what kinds of action on climate change would be dictated if the information on costs and benefits in the SAR were brought together into a cost–benefit framework.

The present paper discusses the pros and cons of the economic valuation of climate change impacts and of various approaches that have been suggested as an alternative to the literature reflected in the IPCC report. Even though not all of these alternatives have an equally firm foundation in economics or ethics, we have recalculated impact estimates for most of them in order to illustrate the sensitivity of impact estimates to such assumptions. Surprisingly, many of the alternative calculations lead to results that we would consider to be within the range of error of the initial figures. In other cases, monetized impact estimates are substantially higher.

In the course of the paper, we touch upon many issues in climate change, economic theory and policy, ethics and decision theory without developing any of them in particular depth. Rather, we deal with these questions as they specifically relate to the issue of climate change impact valuation; readers with a general interest in these topics are referred to the specialized literature. In doing so, we hope to reintroduce the theoretical basis to an important policy debate that has got somewhat out of hand at times. At the same time, the example of climate change can provide some generic insights on the issue of economic valuation of global externalities in general.

The paper is structured as follows. Section 2 briefly reviews the economic assessment of climate change impacts as presented in Pearce *et al.* (1996). Section 3 addresses some of the main technical/methodological issues regarding valuation that were raised in the debate on the chapter. In particular, it deals with the choice between willingness to pay (WTP) and willingness to accept (WTA), the extrapolation of local case-study estimates to other regions and the question of equity weights. Perhaps the most fiercely debated issue, however, has been the valuation of climate-change-induced mortality risk, and the use of regionally differentiated per-unit damage estimates—a notion that follows directly from the logic of WTP / WTA. Section 4 discusses some of the methods that have been put forward to avoid regional differentiation. Another recurring theme has been the claim that monetary impact estimates are redundant and unnecessary for decision making. Section 5 addresses this claim and discusses what role social cost estimates may play in international decision making. Conclusions are drawn in Section 6.

2. Climate change damage costs

The scientific research on global warming impacts has focused predominantly on the so-called '$2 \times CO_2$' benchmark, that is, a scenario with an atmospheric greenhouse gas concentration equivalent to twice the preindustrial CO_2 level. Despite the arbitrariness and limited policy relevance of this scenario, a large part of the social cost chapter in the IPCC Second Assessment Report (SAR) (Pearce *et al.*, 1996) is consequently also devoted to $2 \times CO_2$ damage since the IPCC rules of conduct require that authors focus on existing, and ideally peer-reviewed and published, material. A climate change associated with a doubling of the atmospheric concentration of carbon diode equivalents is expected to occur in the middle of the next century if no substantial emission reductions are realized.

Information on the impacts of global warming is available for several regions and countries. The best studied regions are developed countries, in particular the United States, where climate change impacts have been analysed in a series of studies, following initial work by Smith and Tirpak (1989). The most prominent US studies are made comparable by Smith (1996). The most recent US study is by Mendelsohn and Neumann (1997), which is, however, largely restricted to market sectors. Other OECD regional studies include CRU / ERL (1992) for the European Union (updated by Plambeck and Hope, 1996); Parry and Duncan (1995) for the United Kingdom; and Nishioka *et al.* (1993) for Japan. In the context of an Asian Development Bank (1992) project on climate change in Asia, global warming impacts have also been analysed for a number of Asian countries. Stzrepek and Smith (1995) contains case studies for Africa, Latin America and Asia.

Climate change is expected to affect a wide range of sectors, including agriculture, coastal zones, energy supply and demand, water resources, infrastructure, leisure, migration, human health, human mortality and unmanaged ecosystems. Studies usually deal with only a subset of these impacts and are often restricted to a description of impacts in physical terms. Estimates generally combine, but do not neatly separate the costs of adaptation (such as sea-level-rise protection) and the costs of residual damages (such as the inundation of unprotected areas). See Tol *et al.* (1997) for more discussion and an attempt to single out adaptation costs.

By far the best studied impact categories are agricultural impacts (e.g., Rosenzweig and Parry, 1994; Adams *et al.*, 1994; Darwin *et al.*, 1995; Schimmelpfennig *et al.*, 1996; Reilly *et al.*, 1996) and the costs of sea level rise (e.g., Fankhauser, 1995b; Turner *et al.*, 1995; Yohe *et al.*, 1995, 1996; Bijlsma *et al.*, 1996). Attempts at a comprehensive monetary quantification of all impacts are relatively rare, and usually restricted to the United States (Cline, 1992; Nordhaus, 1991; Titus, 1992). Preliminary estimates of monetary impacts in different world regions are provided by Fankhauser (1995a), Tol (1995), and, subsequent to the finalization of the SAR, Mendelsohn *et al.* (1996). The Fankhauser and Tol figures, which were at the core of the IPCC assessment (Pearce *et al.*, 1996), are reproduced in Table 1.

Fankhauser and Tol (1997) have recalculated the initial set of estimates consistently correcting for purchasing power parity and using the same benefit transfer methodology throughout. The results are reproduced in Table 2. The effect is to raise non-OECD damages by about 40–60 per cent,

Table 1. *Annual monetized 2 × CO_2 damage costs in different world regions*

	Fankhauser bn$	*%GDP*[a]	*Tol bn$*	*%GDP*[a]
European Union	63.6	1.4		
United States	61.0	1.3		
Other OECD	55.9	1.4		
OECD America			74.2	1.5
OECD Europe			56.5	1.3
OECD Pacific			59.0	2.8
Total OECD	*180.5*	*1.3*	*189.5*	*1.6*
E. Europe/Former USSR	18.2[b]	0.7[b]	−7.9	−0.3
Centrally Planned Asia	16.7[c]	4.7[c]	18.0	5.2
South and South East Asia			53.5	8.6
Africa			30.3	8.7
Latin America			31.0	4.3
Middle East			1.3	4.1
Total Non-OECD	*89.1*	*1.6*	*126.2*	*2.7*
World	*269.6*	*1.4*	*315.7*	*1.9*

[a] Note that the GDP base may differ between the studies
[b] Former Soviet Union only
[c] China only
Source: Pearce *et al.* (1996), based on Fankhauser (1995a), and Tol (1995).

Table 2. *Annual monetized 2 × CO_2 damage costs in different world regions with full PPP correction*

	Fankhauser bn$	*%GDP[a]*	*Tol bn$*	*%GDP[a]*
European Union	63.6	1.4		
United States	61.0	1.3		
Other OECD	55.9	1.2		
OECD America			74.5	1.5
OECD Europe			57.4	1.6
OECD Pacific			60.7	3.8
Total OECD	*180.5*	*1.3*	*192.7*	*1.9*
E. Europe/Former USSR	29.8[b]	0.4[b]	−14.8	−0.4
Centrally Planned Asia	50.7[c]	2.9[c]	−4.0	−0.1
South and South East Asia			92.2	5.3
Africa			46.4	6.9
Latin America			40.3	3.1
Middle East			11.5	5.5
Total Non-OECD	*141.6*	*0.9*	*172.8*	*1.7*
World	*322.0*	*1.1*	*364.4*	*1.8*

[a] Purchasing power parity corrected GDP; note that the GDP base may differ between the studies
[b] Former Soviet Union only
[c] China only
Source: Fankhauser and Tol (1997), based on Fankhauser (1995a), and Tol (1995).

and global damages by 15–20 per cent. Based on these and other available figures, Pearce *et al.* (1996) suggest the following aggregate impact estimates for 2 × CO_2:

World damage:	1.5 to 2.0 per cent of world GNP
Developed country damage:	1.0 to 1.5 per cent of national GNP
Developing country damage:	2.0 to 9.0 per cent of national GNP.

Pearce *et al.* (1996) stress the preliminary character of these estimates. In particular, it should be noted that the above figures are best-guess estimates. The range does not reflect a confidence interval, but the variation of estimates found in the literature.

There is a considerable range of error which has not been quantified. The chapter also notes that:

- A large number of likely impacts could not be measured or could only be partially measured. This is particularly the case for non-market damages.
- Figures on developing countries, because they are often based on approximation and extrapolation, are clearly less reliable than those for developed regions.
- As best-guess estimates, the figures neglect the possibility of impact surprises (such as social and political unrest) and of low probability/ high impact events (such as a shut down of the ocean conveyor belt).
- To avoid long-term predictions, damage figures measure the impact of

$2 \times CO_2$ on a society with today's structure. Vulnerability is likely to change as regions develop and population grows, but the direction of this change is unclear because increased risks could be more than offset by adaptation.

In recent work carried out subsequent to the SAR, Mendelsohn and Neumann (1997) suggest that, at least in the market sector in the USA, climate change may have net benefits, contrary to the general thrust of Pearce *et al.* (1996). Budyko (1996) shares this opinion. In yet unpublished work, Mendelsohn *et al.* (1996) extend the US analysis to the world, finding a net benefit for the world as a whole, but a loss in less developed countries. Despite these discrepancies and the above shortcomings, available figures give a rough indication of the possible order of magnitude of $2 \times CO_2$ impact and the relative vulnerability of various regions. One result that appears relatively robust is the higher vulnerability of developing countries compared to developed regions (see Tables 1 and 2). Reasons for this difference include the greater importance of agriculture in these countries[1] the lower level of public health and the tighter financial, institutional and knowledge constraints on adaptation. Below, we ignore the international study of Mendelsohn *et al.* (1997) because it is restricted to market sectors, whereas most of the discussion is on non-market goods and services.

3. Valuation issues

As the previous section makes clear, greenhouse damage estimates still have a number of limitations. This paper concentrates on shortcomings related to the economic valuation of impacts, although issues such as the lack or limited quality of physical impact data (and hence the comprehensiveness of the estimates), the limited treatment of uncertainty and the artificial nature of the $2 \times CO_2$ scenario are arguably at least as important. Economic valuation, particularly valuation of human mortality risks, has been at the centre of the debate on the IPCC 'social cost' chapter.

A number of issues concern valuation techniques as such. The first is the choice between the two concepts of willingness to pay (WTP) and willingness to accept compensation (WTA), which in the case of climate change is essentially an issue of property rights. A second issue is the question of benefit transfer, which asks how estimates for one region or one problem area can be extrapolated to another. A third issue concerns the incorporation of equity issues into the comparison and aggregation of estimates. This section deals with each of these points in turn.

3.1 Willingness to pay vs willingness to accept

It is a well known empirical fact that economic values derived under a WTP framework tend to differ from estimates that measure the same damage using WTA. The latter can be several times higher. Bateman and

[1] With the exception of Darwin *et al.* (1995), agricultural studies continue to suggest predominantly negative impacts in developing countries, although certain countries could benefit. The Darwin *et al.* study has not yet been taken up in aggregate impact assessments.

Turner (1993), for example, report ratios of WTA over WTP ranging from 1.6 to 6.5. Various reasons for this discrepancy have been advanced (see, for example Coursey *et al.*, 1987; Kahneman and Tversky, 1979; and Hahnemann, 1991), but the issue remains unresolved—some argue the difference to be largely a measurement error; some see it as a genuine effect. For practical reasons, Arrow *et al.* (1993) have recommended the use of WTP for contingent valuation studies, since they tend to produce more reliable results. They also indicate, however, that contingent valuation tends to overestimate the true WTP.

The choice between WTP and WTA constitute an implicit statement about prevailing property rights, and this is sometimes used as a guideline for the choice of concept. By using WTP, i.e., asking people how much they would pay to avoid adverse impacts, a changing climate is implicitly chosen as the reference scenario. People do not have a 'right' to the climate currently observed, but have to pay to obtain it. Conversely, by using WTA, the assumption is that people are entitled to a preindustrial climate (and standard of living?) or at the least the current climate plus, perhaps, warming that has already been committed. WTA then estimates the reimbursement needed to compensate for damage arising from alterations to the baseline climate.

However, the appropriate allocation of property rights (and thus the choice between WTP and WTA) in the case of climate change is unclear. On the one hand, the right of future generations to a functioning environment seems hard to question and is at the core of such notions as sustainable development. This would point toward the use of WTA (assuming that climate change is predominantly harmful): future generations have to be compensated for a climate-change-induced deterioration in their living standards. On the other hand, an equally strong case can be made for the right of developing countries to increase their standard of living, which for all realistic scenarios implies increased baseline warming,[2] and hence the use of WTP. A proponent of this second view is Schelling (1995), who also stresses the need to be consistent between concern about the enhanced greenhouse effect (which will mainly affect the future poor) and concern for the fate of today's poor. The issue of property rights remains unresolved.

In practice, WTP and WTA are often mixed up in actual valuation. This is particularly the case for climate change damages, where the limited number of original studies make it necessary to use whatever information is available, often resorting to benefit transfer. Consequently, estimates tend to be a blend of various approaches, although WTP is perhaps more frequently used. Most estimates in the literature were derived with the benefits of emission reductions in mind, and consequently took business-as-usual climate change as the starting point, asking people about their WTP to obtain a deviation. WTA has also been used, however, as have

[2] Even if developed countries substantially reduced their greenhouse gas emissions, developing countries could not increase their living standards to, say, today's OECD level without a further increase in atmospheric carbon concentration.

been a number of second-best measures that were used as approximations in the absence of primary studies. Estimates for the value of a statistical life (VOSL), for example, were derived from a series of predominantly WTA studies (wage-risk studies).

VOSL measures people's attitude to mortality risk. However, an increased risk of death from the point of view of the individual translates into a higher number of casualties from the point of view of society. If 100,000 people are exposed to a 1/100,000 risk of premature death, there will, statistically, be one such death. Suppose that each individual has to be compensated by \$15 to be willing to accept this risk. The total compensation needed is then \$15 $\times$ 100,000 = \$1.5m, for a risk equivalent to one statistical death. This is referred to as the 'value of statistical life' (VOSL). Notice that VOSL is effectively an aggregation rule, a way of adding up individuals' valuation of risk. It is not the value of a 'life'.

At least as far as the current generation of impact estimates is concerned, the distinction between WTP and WTA is thus blurred. Nevertheless, the issue is important conceptually and it is likely to become increasingly relevant as refinements in damage analysis take place and additional studies are undertaken.

3.2 Benefit transfer and scaling by income

Since primary WTP/WTA data for climate change impacts are still scarce, the damage-cost literature relies heavily on what is called benefit transfer. The term refers to an often used short-cut in valuation, in which WTP/WTA results ('environmental benefits') obtained in one study are transferred to a new problem and another site. For the assessment of climate-change-induced mortality risk, for example, per-unit values were 'transferred' from a wide range of VOSL studies in various developed countries, most of them using wage differentials (a WTA procedure called the hedonic approach, see, e.g., Viscusi, 1993)

Benefit transfer is not without problems. Estimates are often site- or problem-specific and hence difficult to transfer. In the case of climate-change-induced mortality, for example, the underlying study and the climate-change application differ both with respect to the analysed hazard and the socio-economic groups exposed. Primary studies are mostly concerned with occupational hazard, while climate-change-related risks primarily relate to extreme weather events, heat stress an other climate-dependent diseases. It is well known that people have a different WTP/WTA depending on the type of hazard—for example, whether it is natural or man-made, voluntarily taken or imposed by others. It is also conceivable that the WTP/WTA of the elderly, who will be most at risk from climate-change-related heat stress, is different from that of workers in the prime of their life, who are the main victims of occupational hazard. For other climate-change-related risks (e.g., malaria, or extreme events), the WTP/WTA may be different again.

To take such effects into account, the values from the underlying study should ideally be corrected for differences in site and socio-economic conditions. Even so, the accuracy of benefit transfer remains open to question. In a direct test of the method, Bergland *et al.* (1995), for example, found a statistically significant difference between estimates based on benefit transfer and the results from a primary study. Alberini *et al.* (1995), on the other hand, secure a consistent set of results for contingent valuation and income-adjusted benefit transfer in a study on morbidity in Taiwan.

If these problems are borne in mind, transferred estimates can provide useful ballpark figures, and the method is often used in situations where the accuracy sought does not justify the costs of a primary study. As for climate change, the use of benefit transfer is primarily necessitated by the absence of primary studies for a large number of countries and impact categories.

In most climate change impact studies, per-unit value estimates were more or less directly transferred from the study site. The only major adjustment made concerned income, which is one of the main explanatory variables for both WTP and WTA. A standard assumption is that WTP / WTA is an increasing function of income.[3] A rich person would normally be willing (and able) to make a higher payment, in absolute terms, than a poor person. By the same token, a compensation of, say $1,000 will appear less attractive to a rich person than to a poor individual. The damage studies reviewed in Pearce *et al.* (1996) therefore usually scale per-unit values according to income, i.e. they use lower values in low-income countries. A possible benefit transfer function is

$$V_j = V_i(Y_j / Y_i)^{\beta}$$

where subscript j denotes the new application where the value is 'transferred' to, and i the original study site. V denotes the WTP / WTA estimate, Y is per capita income, and β is a scaling parameter, i.e., the income elasticity of marginal utility or the income elasticity of demand. Although there is clear empirical evidence for an income effect, little is known about its magnitude and scaling is correspondingly controversial. Most of the studies surveyed in Pearce *et al.* (1996) assume an income elasticity of WTP / WTA of 1, or slightly higher, following an early study by Pearce (1980). That is, WTP / WTA as proportions of income are identical across individuals. If a rich person is willing to pay, say, 5% of his income for an environmental good, a poor person would equally be willing to spend 5% of his.

Recent results cast doubt on the assumption of a unitary income elasticity of WTP / WTA, suggesting an income elasticity of less than one (Flores and Carson, 1997; Kriström and Riera, 1996; see also Krupnick *et al.*, 1996). Given the logic of scaling, a lower income elasticity would imply that damages in developing countries were underestimated initially. (The estimates for developed countries are not affected, since they are the subject of the original study.) The evidence is not yet conclusive. In the case of mortality risk, the few available studies that directly estimate the VOSL in developing countries all came up with substantially lower values than would be obtained through benefit transfer. Thus, Parikh *et al.* (1994) found VOSLs in Bombay of $25,000 using the human capital approach;

[3] Although the theoretical work of Flores and Carson (1997) does not exclude the possibility of a negative correlation.

$20,000 using the wage differential approach and $15,000 based on the Indian Workman's Compensation Act. Da Motta *et al.* (1993) find a VOSL of $15,000 using the human capital approach in Brazil. For comparison, the lowest VOSL assumed in the IPCC social cost chapter is $150,000. The IPCC value is based on an elasticity of WTP / WTA of about one. The Brazilian and Indian evidence would thus imply an elasticity much greater than one. It is worth noting, though, that the human capital approach is largely discredited as an approach to estimating VOSLs (Freeman, 1993). It is also well known that WTP / WTA is likely to exceed the expected value of forgone earnings. It is therefore likely that the Brazilian study has underestimated the true VOSL.

Better information is clearly needed in this area. At the same time, it should be recalled that the question of the income elasticity of WTP / WTA has arisen only because of the absence of original impact research, which necessitated the use of benefit transfer. Although benefit transfer is likely to continue to be important, primary studies directly concerned with the valuation of climate change impact are therefore at least as important as refinements in benefit transfer. With an increasing number of such studies, issues of benefit transfer will automatically become less relevant. In the meantime, and until clear empirical evidence becomes available, it will be important for subsequent impact assessments to explore the sensitivity of estimates to crucial parameters such as the income elasticity of WTP / WTA.

3.3 Equity weighting

A central feature of the WTP / WTA concept is the key role it assigns to individual preferences. The underlying ethical position is that the value of goods should be set according to people's own appreciation of them. At the same time, the socio-economic situation from which people make their assessment is taken as given. This can lead to problems if the currently observed situation (say, the distribution of income) is considered to be unfair. WTP / WTA estimates, because they are a function of socio-economic characteristics, will automatically reflect this unfairness. For this reason, some authors have called for the use of uniform per-unit damage values (see Section 4). The issue is not new, however, and has a long history in cost–benefit analysis (see, e.g., Pearce, 1986). The solution offered by welfare economics is not to use uniform per-unit values, but to weight individual estimates by a corrective factor that adjusts values for inequalities in the income distribution. These 'equity weights' are usually derived from a social welfare function. Consequently they strongly depend on the analyst's or policy makers' value judgment and on the welfare function they endorse. Since there is no universally valid welfare function, it follows that there is no unique set of equity weights.

None of the estimates in Pearce *et al.* (1996) was equity-weighted, although the chapter did show very clearly how such equity weighting could be carried out. In addition, equity was the subject of two separate chapters in the SAR: Banuri *et al.* (1996), and Arrow *et al.* (1996). Unfortunately, none of these chapters pursued the issue of equity weighting. In Fankhauser *et al.* (1997), we have filled this gap and calculated

Table 3. *Equity-weighted climate change damage costs*

	Fankhauser (1995a)	*Tol (1995)*
Uncorrected impact[a]	322.0	364.4
Utilitarian Welfare Function		
$e = 0.0$[b]	322.0	364.4
$e = 0.5$	315.6	411.4
$e = 1.0$	405.2	614.3
$e = 1.5$	621.9	1057.6
$e = 2.0$	1041.7	1930.0
Bernoulli–Nash Welfare Function[c]	405.2	614.3
Maximum Welfare Function		
$e = 0.0$	50.7	46.4
$e = 0.5$	95.8	89.4
$e = 1.0$	181.0	172.2
$e = 1.5$	342.7	331.8
$e = 2.0$	646.5	639.3

[a] As in Table 2.
[b] e denotes the income elasticity of marginal utility (parameter of the utility function).
[c] Bernoulli–Nash weights are independent of e, and correspond to the case $e = 1$ of the utilitarian welfare function.
Source: Fankhauser *et al.* (1997), based on indicated sources.

equity weights and the corresponding damage figures for a variety of possible welfare and utility functions. A selection of results is reproduced in Table 3. As the table makes clear, estimates are highly sensitive to the assumed welfare concept.

4. The pursuit of uniform per-unit values

Perhaps the main objection to the damage numbers reported in the IPCC WGIII SAR was the fact that most studies used regionally differentiated per-unit values—a common practice in valuation and a direct consequence of the WTP / WTA approach (see Section 3). The regional assessment was included in Pearce *et al.* (1996) not least in order to emphasize the differences in vulnerability. It was also expected that regionalized estimates would be closer to the reality of national decision makers. Nevertheless, some critics considered the notion of regionally differentiated values as unethical, particularly in the context of increased mortality risks.

In the course of the debate, several alternatives were put forward, generally aiming at an uniform valuation of mortality risks for all individuals. The most important suggestions are discussed below.

4.1 Averaging

WTP / WTA estimates do not only differ between nations, but also between different socio-economic groups within one country. A pragmatic approach to valuation that is sometimes taken in a national context is to use nationally averaged per-unit values for everybody. The UK Department for Transport, for example, has long used a standardized VOSL in road

Table 4. *Mortality costs with regionally differentiated, globally averaged and maximum per-unit values—Fankhauser (1995a) assessment*

Region[a]	*Deaths* *(10^3)*	*VOSL*[b] *(10^6\$)*	*Loss* *(10^9\$)*	*VOSL*[c] *(10^6\$)*	*Loss* *(10^9)*	*VOSL*[d] *(10^6\$)*	*Loss* *(10^9\$)*
EU	9	1.50	13	0.35	3	1.50	13
USA	7	1.50	10	0.35	2	1.50	10
OOECD	8	1.50	12	0.35	3	1.50	12
fSU	8	0.30	2	0.35	3	1.50	12
China	30	0.10	3	0.35	11	1.50	45
RoW	85	0.13	11	0.35	30	1.50	127
World	120	0.35[e]	51[f]	0.35	51[f]	1.50	219[f]

[a] Acronyms stand for, respectively: European Union, United States of America, Other member countries of the Organization for Economic Cooperation and Development, former Soviet Union, China and Rest of the World.
[b] As in original study.
[c] Global average.
[d] Maximum.
[e] Implied.
[f] Simple sum.

construction appraisal. This VOSL is based on surveys of the literature pertaining to Europe and North America, although the current (1996) valuation of about US\$1.2 million is acknowledged to be well below the average arising from such studies (about US\$2.5 million). With this method, it is recognized that some affected groups may have a higher WTP / WTA than others. However, for ease of calculation and to assure the acceptability of the assessment to all stakeholders, uniform values are used for all population groups. Moreover, if necessary, compensatory policies to restore inequities resulting from such valuation may be installed.

For the same reason of acceptability, the use of uniform, globally averaged values has also been advocated for the assessment of climate-change-induced mortality risks (and also for other impact categories). In Tables 4 and 5 we have calculated the mortality damage that would result from such a method. As expected, averaging leads to lower damages in high-income regions, where per-unit damage values are above world average, and to higher damage in low-income regions, where per-unit values are below world average.

The most striking result is that, abstracting from rounding effects, the revised figures for global mortality damage remain unchanged compared to the initial figures reported in Pearce *et al.* (1996). The reason for this lies in a crucial assumption made by both Fankhauser (1995a) and Tol (1995). In both studies mortality is assumed to be directly proportional to population. That is, the number of climate-change statistical deaths per thousand people is identical in each region and averaging therefore has no effect on total damage.[4] The linearity assumption on mortality changes

[4] Let m be the fraction of the population affected by climate change. By assumption m is identical for all regions. If p_i denotes the population of region i, the number

Table 5. *Mortality costs with regionally differentiated, globally averaged and maximum per-unit values—Tol (1995) Assessment.*

Region[a]	*Deaths* *(10^3)*	*VOSL*[b] *(10^6$)*	*Loss* *(10^9$)*	*VOSL*[c] *(10^6$)*	*Loss* *(10^9$)*	*VOSL*[d] *(10^6$)*	*Loss* *(10^9$)*
OECD-A	11	3.43	38	0.92	10	3.43	38
OECD-E	15	2.07	31	0.92	14	3.43	52
OECD-P	13	2.27	29	0.92	12	3.43	44
CEE&fSU	15	1.43	22	0.92	14	3.43	52
ME	2	0.31	1	0.92	2	3.43	6
LA	22	0.75	16	0.92	20	3.43	74
S&SEA	68	0.44	30	0.92	63	3.43	235
CPA	52	0.66	34	0.92	47	3.43	177
AFR	26	0.43	11	0.92	24	3.43	90
World	223	0.95[e]	211[f]	0.92	204[f]	3.43	766[f]

[a] Acronyms stand for, respectively, OECD-America, OECD-Europe, OECD-Pacific, Central and Eastern Europe and the former Soviet Union, Middle East, Latin America, South and Southeast Asia, Centrally Planned Asia and Africa.
[b] As in original study, i.e., $250,000 plus 175 times the per capita income; note that per capita income is here corrected for purchasing power parity.
[c] Global average, i.e., $250,000 plus 175 times the global average per capita income.
[d] Maximum.
[e] Implied.
[f] Simple sum.
Source: Own calculations based on indicated sources.

was a reasonable 'first cut' at the time. More recent work on heat stress (Kalkstein and Tan, 1995) and tropical diseases (e.g., Martens *et al*., 1994, 1995) demonstrates, however, that mortality changes are not likely to be homogeneous over the globe. In that case, the use of average and regionally differentiated per-unit values will produce different results.

While the use of average values seems to be a pragmatic way forward in general, a main problem with the method is that it may lead to inconsistencies in the way locally and globally caused damages are measured. Evidently, environmental problems of local origin, such as those related to air pollution, would continue to be assessed at locally relevant per-unit values. However, the result may then be large discrepancies in valuation,

of casualties in that region is mp_i. Let v_i be the VOSL in region i, and v the globally averaged value. Global damage using the average value, v, is thus $\Sigma mp_i v$. This expression can then be rewritten as

$$\Sigma mp_i v = \Sigma mp_i\left(\frac{\Sigma v_i p_i}{\Sigma p_i}\right) = m\Sigma p_i \frac{\Sigma v_i p_v}{\Sigma p_i} = \Sigma mp_i v_i$$

which is the expression for global damage using region-specific per-unit values. In the case of benefit-transfers, one may prefer not to use the average of inferred VOSLs, v, but the VOSL associated with the average per capita income. In this case, a further condition is required for identity: VOSL has to be linear in income. In Fankhauser (1995a) this is the case, while Tol (1995) assumes some modest non-linearity—which explains the slight deviations in Table 5.

depending on the origin of the risk. The incremental mortality risk from climate-change-induced malaria, for example, would be valued differently to, say, the same increase in risk caused by deteriorating medical standards. Similarly, traffic-related mortality risks would be valued differently to heat-stress-related risks. This would not only be logically inconsistent, but ultimately it may also lead to an unjustified reallocation of safety investments (e.g., for developing countries, an overinvestment in greenhouse-gas emission reduction at the expense of, say, general improvements in health care; for developed countries, an underinvestment in greenhouse-gas emission reduction to the benefit of, say, traffic safety).[5]

4.2 Maximum value

The use of global averages for VOSL in climate valuation studies would be more or less consistent with national approaches to the use of nationally averaged VOSLs. What would not be consistent, however, is the use of the highest country-average VOSL for the world. This approach has been recommended by Meyer and Cooper (1995), on the grounds that no other value would be acceptable to the country with the highest VOSL. The last columns of Tables 4 and 5 show what would happen to mortality damage if this principle was adopted.

However, the Meyer and Cooper argument is untenable, for the same reasons that mar the use of average values, except that the case against maximum values is much stronger. Using a maximum value for a statistical life would lead to an overemphasis of climate-change-related mortality risks compared to other mortality risks for all countries but the one with the highest VOSL. Moreover, if use of the highest value were justified, it would have to apply within a country as well, i.e., the single individual with the highest valuation would dictate all values; equity within a nation should not be different to equity between nations.

4.3 Historical responsibility and polluter pays

The uniform use of per-unit values at OECD levels has also been advocated by Ekins (1995) and Hohmeyer and Gärtner (1992). In an aberration of the polluter-pays principle, these authors argue that, because OECD countries are predominantly responsible for the accumulation of greenhouse gases in the atmosphere, it is justifiable to value all damages at the per-unit values observed in these countries.

There is a series of problems with this approach. Perhaps the main one is the unfortunate combination of valuation (which, although grounded on value judgements and intertwined with politics, is essentially a technical–empirical matter) with the political question of equity and compensation. What the polluter-pays principle provides is a rule about the direction of compensation payments (from the polluter to the victim), and that payments should somehow reflect inflicted damages. It does not,

[5] The optimality of investment is considered from a global point of view. Because climate change is a global externality and benefits will predominantly occur elsewhere, domestic decision makers have an additional incentive to underinvest in climate change prevention.

however, provide a methodology to determine these damages. For this it relies on conventional valuation techniques.

A second problem with the approach is that it reverses common practice in litigation cases, where compensatory payments are determined according to the damage suffered by the victim. Instead, the approach suggested by Ekins and Hohmeyer and Gärtner determines damage as the welfare loss the offender would have suffered, had he been the victim. This has no counterpart in domestic or international law. Clearly, what matters is the damage suffered by the victim.

A third, more practical problem is that impact estimates now crucially depend on who is perceived to be responsible for which part of the inflicted damage. Assigning responsibility, however, is a complicated matter. The facts may be clear at first sight—OECD countries have contributed most to the accumulation of greenhouse gases in the atmosphere—but on closer consideration the case is not so straightforward. For example, to what extent can countries be held responsible for actions, the consequences of which they were not aware of? Should they have been aware of Svante Arrhenius's work on the subject a hundred years ago? Is collective responsibility the same as individual responsibility? Could early greenhouse-gas abatement have created other problems? How should these be taken into account, if at all? What happens in the near future when developing countries become the predominant emitters of greenhouse gases?

It is not the purpose of this paper to enter into this debate. The point we want to make, though, is twofold. First, the concept of responsibility depends strongly on the ethical position of the person, nation or generation affected by climate change, as well as on whether this person, nation or generation is guided by what is or by what ought to be. Second, an open debate about accountability is clearly necessary, but responsibility, however it is apportioned, does not determine the welfare loss people will suffer.

For the purpose of illustration and sensitivity analysis, we have nevertheless calculated the 'damages' that would result from the Ekins and Hohmeyer/Gaertner approach. Contrary to these authors, however, we acknowledge the difficulties in assigning responsibility and work with different assumptions on accountability. The results are provided in Table 6. We distinguish between OECD countries only and the Annex I countries of the Climate Convention (approximated in the calculations as OECD plus countries of the former Soviet Union). The table also distinguishes between various degrees of responsibility. The rich region (OECD / Annex I) is either held fully responsible for all damages, or for its own damages plus a fraction of damage in poor countries determined by its historic contribution to greenhouse-gas emissions.

In Table 6, the first column reproduces the Fankhauser damage estimates of Table 2. The next two columns re-estimate 'damage' on the assumption that impacts for which the rich region is responsible are valued at the average per-unit values of that region. In the second column, the rich region is held responsible for all impacts, and hence all 'damage' in the poor region is valued at the level of the rich. In the third column the rich

Table 6. *Fankhauser's estimates for different positions on valuation and accountability (damage as percentage of GDP)*

Region	*Original*[a]	*Valuation*[b]		*Accountability*[c]		
		All[d]	*64/84*[e]	*All*[d]	*64/84*[e]	*64/84*[f]
OECD	1.36	1.36	1.36	2.42	2.04	1.55
Non-OECD	0.86	6.86	4.39	0.00	0.31	0.70
World	1.08	4.41	3.04	1.08	1.08	1.08
Annex-I	0.99	0.99	0.99	1.52	1.44	1.28
Non-Annex	1.29	7.77	6.52	0.00	0.21	0.60
World	1.08	2.96	2.60	1.08	1.08	1.08

[a] As in Table 2.
[b] Values in the poor region (non-OECD and non-Annex, respectively) are adjusted to the values in the rich region (using factors 8 and 6, respectively).
[c] The rich region (OECD and Annex-I, respectively) compensates the poor region for damage suffered from climate change.
[d] Damages adjusted or compensated for all impacts in poor countries.
[e] Damages adjusted or compensated for 64 per cent (non-OECD) or 84 per cent (non-Annex I) in poor countries. The OECD and Annex-I contributed an estimated 64 per cent and 84 per cent, respectively, to accumulated carbon dioxide emissions from industrial sources (Gruebler and Nakicenovic, 1991).
[f] Rich and poor regions are each held accountable according to their respective contributions as per note e.
Source: Own calculations based on indicated sources.

region is only partially accountable for damages in the poor region. World 'damage' estimates increase by about a factor 2.5 to 4 as a consequence of these assumptions. 'Damages' in developing countries increase by an even larger factor. It is important to note that these figures are based on a method that has little meaning in terms of welfare economics. Perhaps its main disadvantage is that the method no longer reflects the actual welfare loss people will face.

The last three columns of Table 6 adopt a definition of the polluter-pays principle that is closer to the usual interpretation of the concept. 'Polluter pays' is now assumed to mean that responsible regions compensate others for inflicted damage.[6] The table shows the total cost each region would incur under this regime. Costs consist of self-inflicted damages plus compensation paid, minus compensation received. Damage is again valued at regional per-unit values for this exercise, and world damage therefore remains unaltered, compared to Table 2. In column four, the rich are held accountable for all the damage suffered anywhere in the world, and hence meet all damage costs. Net costs to the poor drop to zero. In column five, the rich are held partially accountable (and hence only partially compensate) for damage in poor regions. The sixth column analyses reciprocal responsibility. That is, the rich compensate the poor, and the poor the rich according to their respective contributions to the enhanced greenhouse effect. This last (rather hypothetical) scenario provides results closest to the original figures.

[6] Note that the capital transfers do not necessarily result in an overall benefit for the compensated party.

For simplicity, the results in Table 6 are all based on the regions' shares in the accumulated greenhouse gas emissions up to 1990 (instead of the year in which $2 \times CO_2$ is expected to occur). This biases the assessment in favour of developing countries, whose emissions are growing faster than those of developed countries. That is, their share in future emissions is higher than it was in the past.

4.4 Differentiated values and intergenerational equity

The motives for uniform valuation discussed above largely relate to intragenerational equity. Orthogonal to this issue is that of intergenerational equity. The matter of uniformity of differentiation of values becomes more complicated when one considers the intertemporal consequences of the various positions. Schelling (1995) argues that the rules applied to intragenerational issues should also hold for intergenerational issues.

If one allows differentiation in VOSLs between countries, there seems little reason not to allow differentiation across generations. According to the WTP / WTA logic outlined earlier, one would expect VOSLs to increase over time as per capita income grows. At the same time, mortality losses can be discounted back to their net present value without methodological difficulties, since damages are equivalent to the compensation requested by future generations, or to the income they are willing to forego to avoid damages.

If equity concerns are taken into account by using averages or maximum values, the choice of time horizon becomes an issue. If the practice is to take averages across an entire decision-making unit (e.g., a country), presumably one would also have to take averages over several time periods. How the relevant time horizon would or should be defined is, however, unclear. In the case of a global average, the relevant time horizon may arguably be 'the whole future'. In addition to questions of definition, the more practical issue would be to construct institutions that guarantee that the abstract notion of 'concern for the whole future' is also operationalized in a meaningful way.

5. On the meaning and usefulness of economic values

Economic valuation is by and large associated with cost–benefit analysis (CBA). Authors who oppose CBA have therefore rejected valuation studies as redundant. It is not the purpose of this paper to discuss the merits and shortcomings of CBA, although we are of the opinion that a systematic and careful comparison of monetized 'pros' and 'cons' can produce important insights to decision makers. On the other hand, we would also subscribe to the view that no single approach can produce all the answers. The point to make here, however, is that monetary impact estimates can be useful also outside a CBA context. Even if CBA is pursued, Pearce (1997) argues that the information in the IPCC SAR is sufficient to indicate that much stronger climate controls are called for than currently observed, i.e., benefits of stronger controls exceed the costs. Critics of the SAR must therefore also be faulted for rejecting the CBA approach without investigating what it implied.

5.1 Sustainability

Knowledge about the monetary value of climate change impacts is needed for some interpretations of sustainable development, for example. Sustainability is one of the most prominent notions suggested to guide decision makers (e.g., Howarth and Monahan, 1992). In the economic literature, sustainability is often interpreted to mean a non-decreasing utility level over time (see, e.g., Pezzey, 1989). Hamilton and Ulph (1995) analysed the conditions needed to maintain a non-decreasing utility level in the case of climate change, following the work of Hartwick (1977, 1978) on the sustainable use of renewable resources. According to the modified Hartwick rule derived by Hamilton and Ulph, (weak) sustainability is obtained if investment in each period is equal to the rent on extracted resources, net of the optimal carbon tax yields (the tax needed for emissions to follow an optimal trajectory), plus the value of the change in the atmospheric carbon stock. If this condition holds, utility will be constant over time; that is, future generations will be equally as well off as the current generation. Although there are many other interpretations of sustainability, the example shows that the notion does not necessarily preclude the need for valuation. In order to implement the Hamilton/Ulph rule, information is needed about the economic value of atmospheric carbon, i.e., information about the marginal damage caused by a tonne of emission.

5.2 Impact estimates as inputs to negotiations

Climate change has a variety of impacts, even within a single country. One of the advantages of valuation is that it summarizes the available impact information in a consistent manner. One obvious way to make use of impact estimates could therefore be to use them as inputs in the negotiations for a climate change protocol. In this scenario, impact estimates are not used in a decision support system like CBA, but provide background information for decision makers. Roughly, negotiations could then be modelled as follows. Each party comes to the negotiations equipped with a climate-change damage function for its territory (measured according to the WTP/WTA of its own people), as well as its mitigation cost function, an emission inventory and any other relevant information. On the basis of this information parties can negotiate on mitigation and compensation levels. For each proposal (derived, e.g., from equity arguments such as historical responsibility) it is then possible to calculate the welfare impacts for each party, and this in turn will help parties to determine whether a particular proposal is acceptable, whether it is consistent with equity requirements, and so on.

It is clear that to serve this information purpose, impact estimates would have to reflect the actual regional welfare effects as adequately as possible. They would have to be descriptive in the sense that they take observed facts (e.g., income differences) as given. At the same time, they would have to be objective. Countries would clearly have a strategic interest in estimates that improve their bargaining position. Given the high uncertainty in impact assessment, there is a danger that the estimates themselves may become the subject of negotiations. Arguably, this process can to some extent already be observed in the discussions on the IPCC social cost chapter (Pearce *et al.*, 1996). Although many critics had genuine concerns, there was a tendency for groups to push for estimates that would lend support to the climate policy of their choice. In this situation, 'objective' estimates by an impartial body such as the IPCC may serve a useful function. The regional impact estimates of Pearce *et al.* (1996) should be understood as a first attempt in this direction.

6. Conclusions

The chapter on the social costs of climate change has been one of the most controversial in the IPCC SAR. The purpose of this paper is to discuss some of the main objections raised in the IPCC review process and to show what implications they would have on damage estimation.

The economic valuation of climate change impacts is difficult. As stated in the social cost chapter itself, available figures are still incomplete and have to be interpreted with care. Nevertheless, we would argue that monetary estimates of climate impacts can provide useful information to decision makers. We have argued that monetary estimates may serve a useful purpose whether they are used in a cost–benefit context or not.

However, to be credible, such estimates need to be based on a sound theoretical framework and make use of the best estimation techniques available at the time. In our opinion, *ad hoc* methods such as valuation according to historical responsibility or valuation at the highest observed level do not meet this requirement. Neither of them has sound theoretical foundations and conceptual problems abound. Although not without problems, the WTP / WTA method is the best technique currently available.

Issues of rights and responsibilities are clearly important and finding the right answer to these questions will be crucial for a successful climate change policy—for the discussion of compensation schemes as well as for the allocation of the abatement burden. However, this by no means implies that economic valuation, too, should be a political process, as some sources have asserted (e.g., the equity chapter in the IPCC WGII SAR—Banuri *et al.*, 1996). It is true that valuation theory (like consumer theory) is based on a series of axioms with which not everybody may agree. It is also the case that people's perceptions about rights and duties will influence their WTP / WTA. In that sense economic valuation is 'political'. But this does not mean that damage valuation should become the subject of negotiations. Economic values reflect people's preferences and, although preferences can be influenced in a variety of ways, they cannot be determined in intergovernmental negotiations. Rather, one would expect the converse to be true: that a country's negotiating position is determined by the preferences of its people. This paper shows how sensitive impact estimates are to politically inspired alternatives.

To serve a useful purpose, damage figures have to be of sufficient quality and be firmly based on empirical work. There is a clear need for improved estimates in that respect. Primary studies that value the impacts of climate change directly are particularly needed. Current assessments use benefit transfer. Valuation studies are especially needed for non-market impacts (e.g., on health, human amenity and natural ecosystems), and with respect to impacts in developing countries. The more primary studies are available, the less analysts will have to rely on difficult and controversial benefit transfers. Nevertheless, climate change impacts are so numerous and diverse that the extrapolation of case-study results is likely to remain an important technique for the foreseeable future. The credibility of such results will largely depend on the care with which estimates are transferred from one study site to another.

It should also be recalled that, in addition to valuation issues, impact estimates suffer from a number of limitations not related to valuation. Improvements are also needed in that respect. Among the most important research topics are the need to move from equilibrium ($2 \times CO_2$) to transient or dynamic damage analysis (amongst others to properly estimate marginal impacts), and the need for a better understanding of adaptations. As research is moving in this direction, the Third Assessment Report of the IPCC will hopefully be in a position to provide better-quality (and less controversial) estimates.

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